High efficiency quantum dot solar cells based on multiple exciton generation

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Timeline

- Project start date: Feb. 2008
- Project end date: Jan. 2011
- Percent complete: 75%

Barriers

- Barriers addressed
  - Device efficiency: demonstrate proof of concept to collect multiple exciton generated carriers

Budget

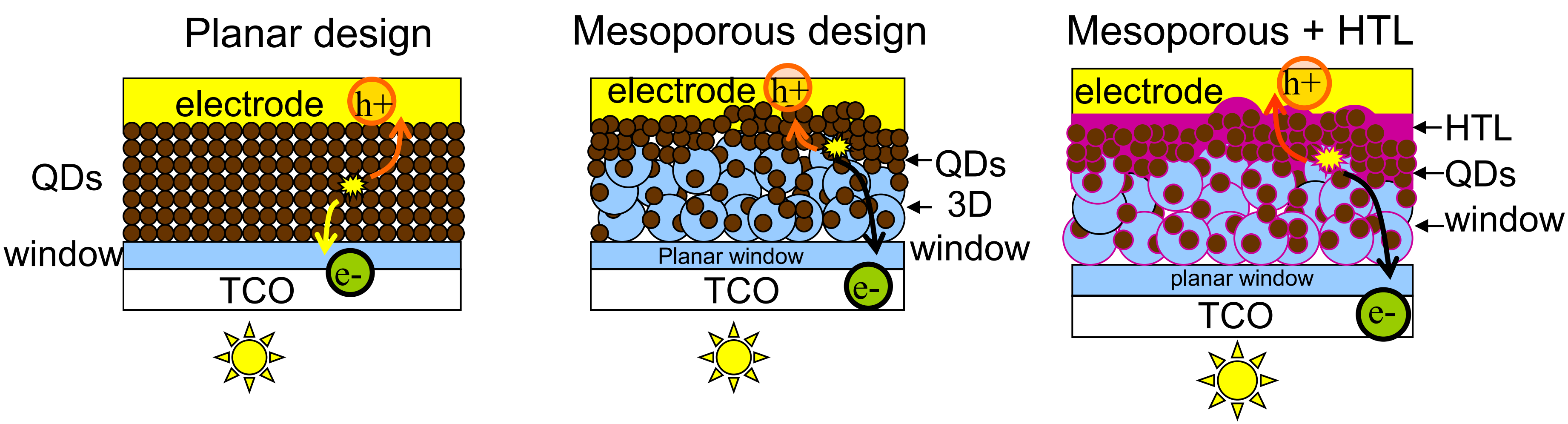
- Total project funding: $1.1M
  - DOE share: $0.9M
  - Contractor share: $0.2M
- Funding received in FY09: $0.3M
- Funding for FY10: $0.3M

Partners

- U.C. Santa Cruz
  - Prof. Sue Carter
  - Prof. Glenn Alers
- Project lead: Alison Breeze

Approach

- Quantum dots: exchange long for short ligands for film formation and to improve charge transport
- Optimize charge generation and transport
  - Charge transfer: new ligands to tune charge transport
  - Recombination: improve passivation to eliminate traps
- Optimize energy level matching of QDs, window and electrode materials
- ALD hole transport layer (HTL) – passivation and transport



Challenges, Barriers or Problems

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- Balancing trade-off between good charge transport against maintaining quantum confinement and MEG carrier generation

- successful integration of hole transport layer on top of QDs while maintaining quantum confinement properties

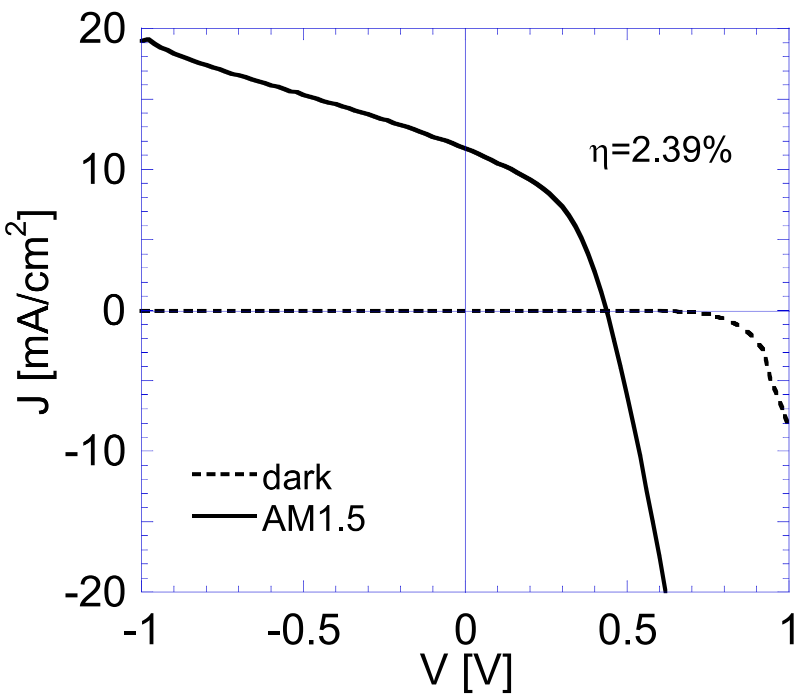
Project Objectives:

- Overall:
  - demonstrate that MEG in quantum dots can dramatically improve maximum efficiency obtainable in PV
  - Expand scientific field's understanding of quantum dot solar cell devices and factors limiting performance
- Year 2: milestone peak IQE=90% → achieved with peak IQE approaching 100%

Ability to harvest multiple exciton generated carriers will allow single junction solar cell efficiencies exceeding Shockley–Queisser limit of 31%

Device Performance

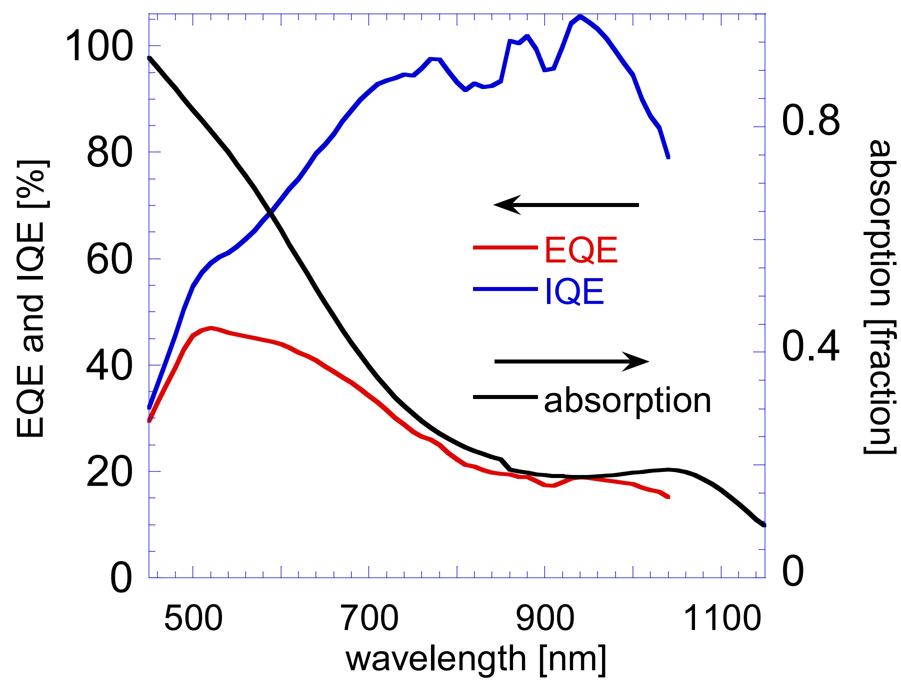
planar device



	V_{oc} [V]	J_{sc} [mA/cm^2]	ff [%]	η [%]
year 1	0.37	10.5	40	1.55
year 2	0.44	11.9	46	2.39

Improvements: deposition and ligand exchange

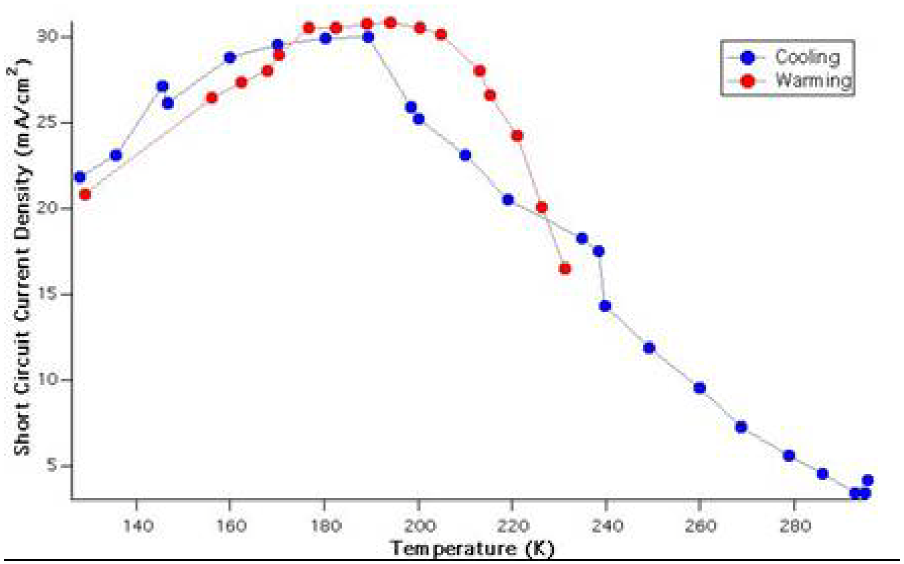
mesoporous device

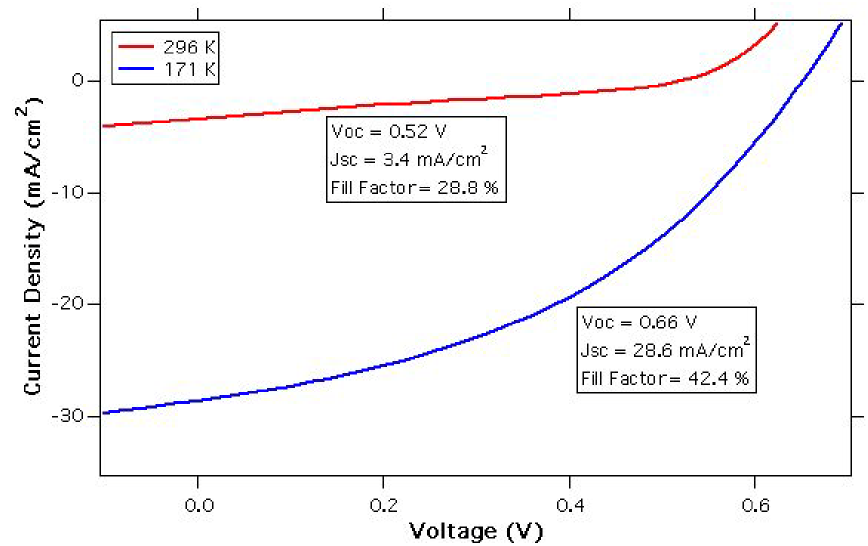


- IQE approaching 100% in near-IR
- Meets year 2 milestone
- IQE = EQE / absorption
- measurement error needs quantification

Temperature Dependence

Mesoporous Device





Mechanism theories:

- Increased particle coupling *via* decreased interparticle distance
- Increased carrier lifetime

Stunning performance improvement for lower temperatures

η~8% under 100mW/cm^2 xenon light source at 171K

Experiment summary and results

experiment	motivation	result
shorter ligands	decrease QD spacing to improve transport	introduced counter-diode / charge suppresion feature, lower η
secondary ligand passivation	decrease recombination	slightly lowered collection efficiency
core/shell QD passivation	decrease recombination	improved passivation but interfered w/ transport; J_{sc} loss
vary window, electrode and QD energy levels	improve charge generation and collection	important factor requiring collective optimization

ALD of Hole Transport Layer

ALD HTL conformably coats mesoporous structure
Integration into quantum dot solar cell architecture in progress

Future Plans

Expand scientific understanding of QDSC functionality and nature of factors limiting device performance

- pinpoint efficiency increase mechanism for low temperature
- elucidate role of ligand on performance beyond interparticle spacing
- understand why short-ligand and additional passivation approaches had detrimental effects
- extensive material and device characterization

Year 3 Milestone: peak internal quantum efficiency IQE > 120%

Apply knowledge to engineer breakthrough performance at room temperature

Collaborations

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U.C. Santa Cruz

- Prof. Sue Carter and Prof. Glenn Alers research groups
- University laboratory and Advanced Studies Laboratory at NASA Ames Research Center
- relationship: sub-contractor within DOE Solar Program
- extensive collaboration

Summary

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- peak IQE approaching 100% in near-IR
- Temperature dependence demonstrates stunning efficiency increase to η~8% at low T
- Two avenues pursued to replicate performance at room temperature
  - increase particle coupling
  - improve surface defect passivation
- Expand material and device characterization

	peak IQE	**peak IQE milestone**	**η under am1.5**
year 1	79%	> 60%	1.56%
year 2	approaching 100%	> 90%	2.39%